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INVESTIGATION OF THE CAUSE OF HYDRAULIC SYSTEM MALFUNCTION OF M--ETC(U)
JUL 78 M E LEPERA, J MESSINA, H MULLINGER

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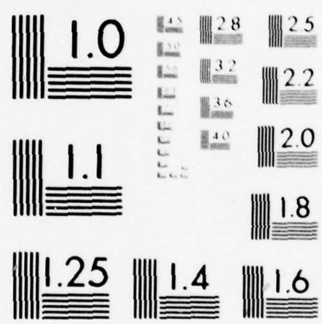

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INVESTIGATION OF THE CAUSE OF HYDRAULIC SYSTEM MALFUNCTION OF M60A1 (AOS) TANKS USING MIL-H-46170 SYNTHETIC-BASE HYDRAULIC FLUID.

9 Final rept.,

by

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~~Chrysler Corp~~

~~and~~

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~~U.S. Air Force~~

11 July 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the investigation by the Chemical Subgroup of the Fire-Resistant Hydraulic Fluid Task Force. The Task Force was organized in 1975–76 to address the problems arising from the introduction of the new "less-flammable" MIL-H-46170, "Hydraulic Fluid, Rust-Inhibited, Synthetic Hydrocarbon Base, Fire-Resistant." The problems were associated with stuck/inoperative servo-valves in the gun control systems of the M60A1 (A0S) tanks. The problems were subsequently identified with one

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company's product which contained a trace amount of a water-coupling inhibitor, polypropylene glycol. The inhibitor in the presence of absorbed moisture caused coprecipitation of the rust inhibitor which deposited on the critical surfaces of spool valve systems.

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METRIC CONVERSION FACTORS

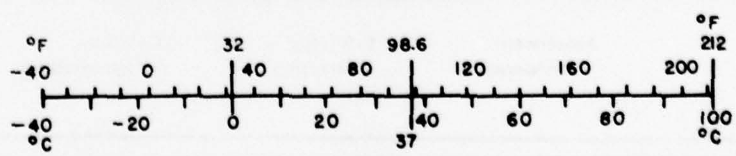
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric tons	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 cm (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric tons (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



INVESTIGATION OF THE CAUSE OF HYDRAULIC SYSTEM MALFUNCTION OF M60 AL (AOS) TANKS USING MIL-H-46170 SYNTHETIC-BASE HYDRAULIC FLUID

I. INTRODUCTION

Interest in poly-α-olefin synthetic hydrocarbons surfaced in 1963. At that time, Sun Oil Company made limited quantities of a number of such fluids available for laboratory evaluations. In 1966, Sun Oil Company published a technical paper describing the preparation and physical and chemical properties of the fluids.[1]

Limited studies at Frankford Arsenal during 1963–64 indicated that the poly-α-olefin oils supplied by Sun Oil Company exhibited high flashpoints ranging from 350° F to 500° F, effective lubricating properties, and excellent thermal and oxidation stabilities. On the basis of these promising laboratory test data, potential use of the fluids for U. S. Army military equipment was envisioned. Unfortunately, Sun Oil Company decided that high-volume use of these fluids did not appear promising; as a result, they discontinued further production and halted all research and development efforts on the fluids.

Concurrent with Army evaluations, the Air Force was engaged in the development of a less flammable hydraulic fluid as a replacement for MIL-H-5606 "Hydraulic Fluid, Petroleum Base, Aircraft and Ordnance," for use in tactical aircraft without retrofit for Southeast Asia.[2,3] Cooperative efforts between the Air Force Materials Laboratory and Mobil Oil Company led to the development of Specification MIL-H-83282, "Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft." The specification was issued in July 1970 with amendments in July 1972 and February 1974. The α-olefin polymer based fluids meeting Specification MIL-H-83282 have flashpoints approximately 212° F higher than MIL-H-5606 hydraulic fluid, are self-extinguishing, and exhibit excellent lubricating properties and oxidation stability to 350° F (400° F in inert environments). Extensive laboratory and field tests conducted by the Air Force on fluids meeting the requirements of Specification MIL-H-83282 resulted in a recommendation that the fire-resistant α-olefin polymer fluid be considered as a replacement for Specification MIL-H-5606 fluid for aircraft hydraulic

[1] I. N. Duling, J. A. Griffith, and R. S. Stearn, "A New Synthetic Hydrocarbon Lubricant for Extreme-Temperature Applications," *ASLE Transactions*, 9, pp 1-12 (1966).

[2] B. A. Loving, R. L. Adamczak, and H. Schwenker, "MLO-68-5, A Less Flammable Hydraulic Fluid for MIL-H-5606 (B) Replacement," Technical Report AFML-TR-71-5 (April 1971).

[3] C. E. Synder and H. Schwenker, "MIL-H-83282, Fire Resistant Hydraulic Fluid," *Materials on the Move*, 6, National Technical Conference Series of the Soceity for the Advancement of Material Process Engineering, (October 1974).

systems. As of this date the Naval Air Systems Command and U. S. Army Aviation Command have adopted MIL-H-83282 as a replacement for MIL-H-5606 in aircraft application.[4,5]

II. LABORATORY AND FIELD TESTS

In December 1973, as a result of the October 1973 Israeli/Arab conflict, the late General C. Abrams, Chief of Staff, expressed concern over the reported incidents of U. S. Army M60 tank turret fires which had occurred as a result of the rupture of hydraulic fluid lines. The hydraulic lines are illustrated in Figure 1. The fires were attributed in part to the highly flammable "Hydraulic Fluid, Petroleum Base, for Preservation and Operation" meeting the requirements of Specification MIL-H-6083 which was used as the hydraulic fluid for U. S. Army tanks. (MIL-H-6083 is similar to MIL-H-5606 except that MIL-H-6083 contains a rust inhibitor.) As a result, considerable interest was stimulated in the potential use of the less flammable α-olefin polymer fluids for tank use.

At a meeting in January 1974 at the M60 Tank Project Manager's Office, Warren, Michigan, a possible replacement for MIL-H-6083 hydraulic fluid was discussed. This meeting was attended by personnel from the Project Manager's Office, Chrysler Defense Engineering, Cadillac Gage, Air Force Materials Laboratory, Naval Air Development Center, Aberdeen Proving Ground, MERADCOM, Rock Island Arsenal, and Frankford Arsenal. A number of possible fluids of less flammability were considered for replacement of the current MIL-H-6083 fluid, but several were of long-range interest and immediate attention was therefore centered on developing a rust-inhibited version of MIL-H-83282, particularly since the latter would be compatible with MIL-H-6083 and MIL-H-5606. Further, the α-olefin fluid would be compatible with current hydraulic systems including hardware, seals, elastomers, paints, etc., thereby providing a direct drain and fill replacement for MIL-H-6083 without the need for any system retrofit. Tests were planned on the fluid to include tank performance tests at moderate temperatures at The Tank Automotive Command; flammability tests at The Ballistics Research Laboratory, Aberdeen Proving Ground; and low-temperature M60A1 (AOS) tank tests (gun and turret) and M60A1 (AOS) tank gun recoil tests at The Test & Evaluation Command, Aberdeen Proving Ground. Frankford Arsenal's assignment was to determine the rust preventive additive to be used and the concentration required. Work centered on α-olefin products which were qualified under Air Force Specification MIL-H-83282, "Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft." Since MIL-H-83282 for aircraft is not a rust-inhibiting type, initial studies were

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[4] Technical Bulletin TB-55-1500-33425, "Conversion of Aircraft to Fire Resistant Hydraulic Fluid," Headquarters, Department of the Army, Washington, D. C. (May 1975).

[5] Teletype R1013427, dated 27 July 1975, from Commander Navair Systems, Washington, D. C.

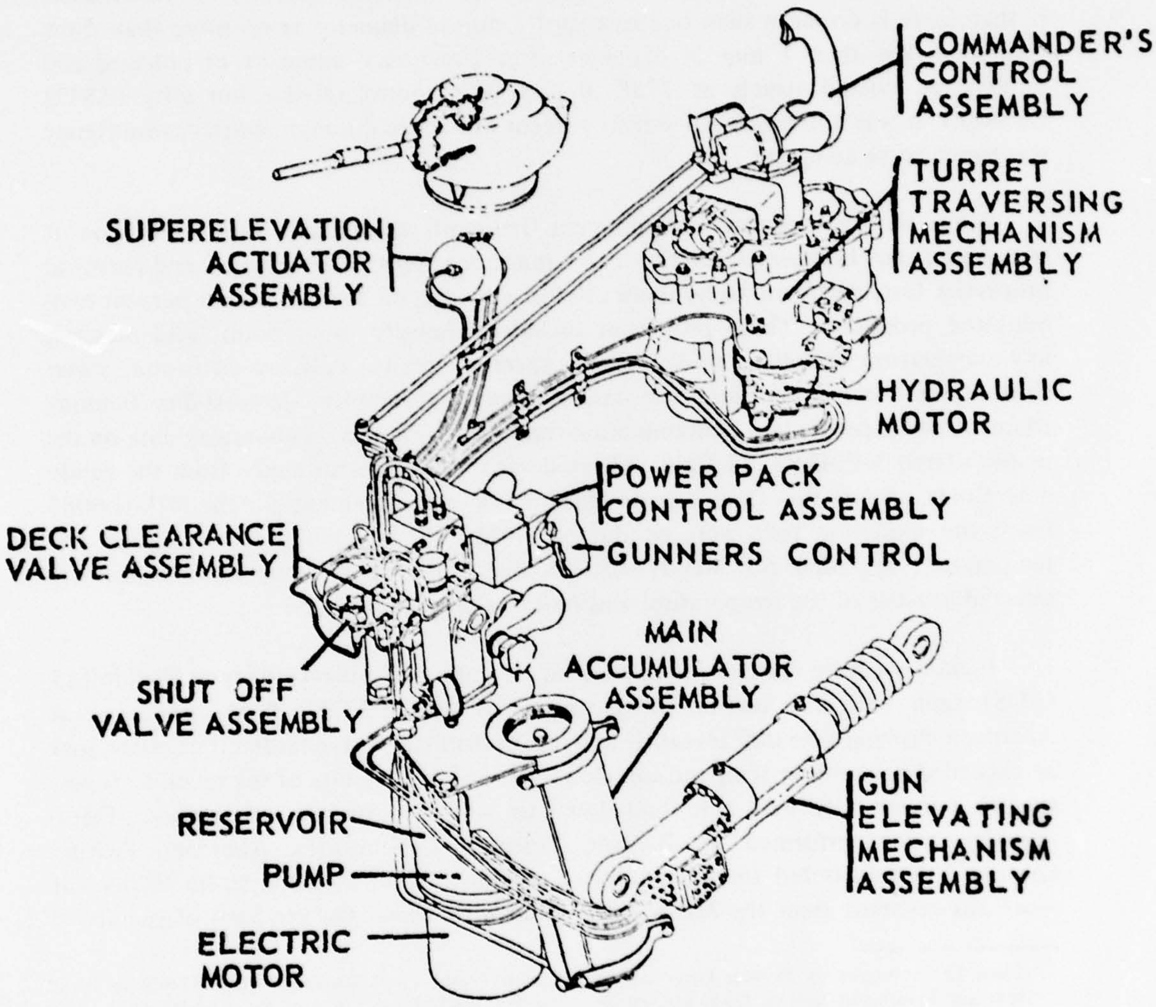

Figure 1. Gun elevating and turret traversing system.

directed toward modifying the MIL-H-83282 compositions to include a rust inhibitor. Preliminary tests were run by adding varying amounts of barium dinonylnaphthalenesulfonate to each of the products qualified under Specification MIL-H-83282. (This rust inhibitor is used in MIL-H-6083 qualified products.) (Criterion of effectiveness is that there is no more than one rust spot 1 mm in diameter or no more than three rust spots less than 1 mm in diameter after 100 hours' exposure of polished and sandblasted coated panels at 77.0° F and 100 percent relative humidity (ASTM D1748).) It was noted that 2.5 weight percent of barium dinonylnaphthalenesulfonate was found to be adequate.

Since the rust-preventive requirement frequently complicates the formulation of hydraulic fluids because of additive interference problems, other physical and chemical properties tests pertinent to hydraulic fluids were run on the 2.5 weight percent rust-inhibited products. These properties included viscosity, pour point, acid number, low-temperature stability, rubber swell, specific gravity, galvanic corrosion, water content, antiwear properties, evaporation, oxidation stability, flammability foaming characteristics, particulate contamination, and bulk modulus. Laboratory data on the rust-inhibited MIL-H-83282 fluid indicated satisfactory performance from the candidate fluids. Since this fluid was designed to be a replacement for the MIL-H-6083 fluid, the oxidation tests were conducted at 250° F, which was the oxidation test temperature specified for MIL-H-6083 fluids. This upper temperature limit was selected because of the temperature sensitivity of the rust inhibitor.

Field tests were carried out as planned. System performance tests on the M60A1 (AOS) tank with the rust-inhibited version of MIL-H-83282 fluid conducted at Aberdeen Proving Ground[6] revealed that all performance standards either were met or exceeded at ambient temperatures down to -25° F. Results of the recoil tests performed concurrently with this fluid down to -45° F were also satisfactory. Flammability tests performed by Ballistic Research Laboratories, Aberdeen Proving Ground[7,8] demonstrated the rust-inhibited version of MIL-H-83282 to be 70 percent more fire-resistant than the MIL-H-6083 fluid now used. On the basis of the above

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6 Final Letter Report on Product Improvement Test of Hydraulic Fluid (Modified MIL-H-83282) in Turret Hydraulic Systems of M60A1 Tank, TECOM Proj. No. 1-VC-08A-060-007, Report No. APG-MT-4452 (April 1974).

7 W. J. Noonan, "Ignition of Aircraft Hydraulic Fluid by Incendiary Ammunition," Ballistics Research Laboratory, Aberdeen Proving Ground, MD, Memorandum Report No. 2246, AD 907652L (November 1972).

8 W. J. Noonan, "The Relative Ignitability of Hydraulic Fluids," Ballistics Research Laboratory, Aberdeen Proving Ground, MD, Interim Memorandum Report No. 204 (March 1974).

laboratory and performance evaluations, the Commander, Army Materiel Command on 29 March 1974 issued an order to adopt the rust-inhibited MIL-H-83282 as a replacement for MIL-H-6083.[9] Frankford Arsenal Purchase Description 5136, "Hydraulic Fluid, Rust Inhibited, Fire Resistant, Synthetic Hydrocarbon Base," was published 19 March 1974.

The use of the fluid in new production M60A1 (AOS) tanks began about July 1974. (Two products, Royal Lubricants "Royco 751" and Bray Oil Company's "Micronic 883" were qualified under Frankford Arsenal Purchase Description (FA PD) 5136.)

Coordination efforts among Army, Navy, Air Force, and Industry culminated in the issuance in March 1975 of a consolidated MIL-H-46170 Specification, "Hydraulic Fluid, Rust-Inhibited, Fire-Resistant, Synthetic Hydrocarbon Base," superseding FA PD 5136.

In the early part of 1975, a series of incidents relating to "stuck valves" in components of new M60A1 (AOS) tanks surfaced. The tanks were new production vehicles and were factory-filled with one of the qualified products, FA PD 5136 (Royal Lubricants Royco 751, Lot 5) hydraulic fluid. The principal problem appeared to be the "sticking" of the power spool valve in the gunner's hydraulic valve control assembly (Figure 2). The clearance between the valve body and spool is 0.0001 inch. These incidents were associated only with the use of the factory-fill Royco 751 product. The first problems with "stuck" valves were encountered in Germany. Analyses of fire-resistant hydraulic (FRH) fluid samples from M60A1 (AOS) tanks in Germany are in Table 1. (The data reported in Table 1 and in subsequent tables in this report represent condensations of the total data obtained in the laboratories of the authors.) Field technicians reported that the severity of valve sticking ranged from easy removal of the spool from the valve body to the need for the use of a drift punch and hammer for removal. Once removed, however, the valve spool could be restored to serviceable condition by simply being wiped with a Kimwipe and being reassembled.

At approximately the same time of the reported incidents in Germany, similar problems were encountered in new production M60A1 (AOS) tanks (with Royco 751, Lot 5) at Camp Pickett, Camp Lejeune, and Quantico (Tables 2, 3, and 4). In one instance, a valve assembly was obtained from Quantico and forwarded to Wright-Patterson Air Force Base for study. The latter reported that there was a coating on the spool, and the laboratory analyses indicated the coating (after the residual oil was removed with heptane) to be gray and gummy. The Spark Source Mass Spectroscopy Technique indicated that the coating contained barium, sulfur, silicon, chlorine, and phosphorus.

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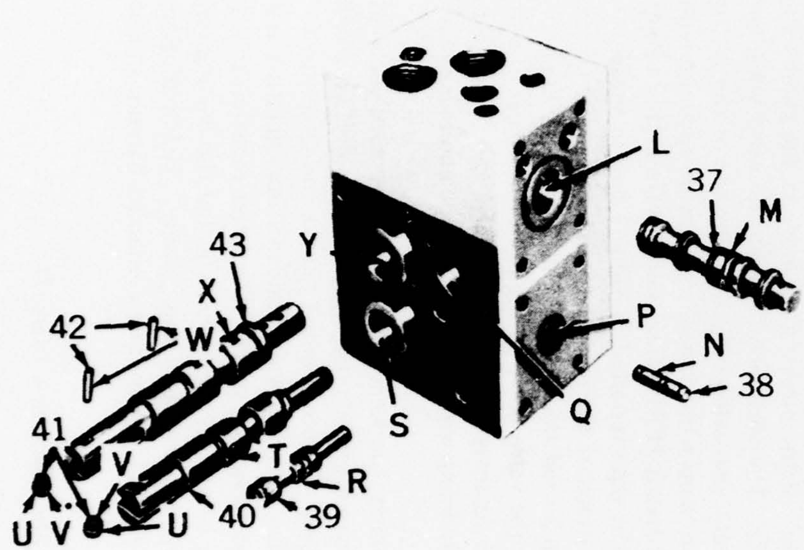
[9] Teletype 092140408, AMC Headquarters, 2 April 1974.



LEGEND

37. POWER SPOOL
38. OVERRIDE SPOOL
39. AUXILIARY PRESSURE REGULATING SPOOL
40. ELEVATING SPOOL
43. TRAVERSING SPOOL

(OVERRIDE PISTON NOT SHOWN)

Figure 2. Sticking Valves on M60A1(AOS) tank valve assembly-hydraulic.

Table 1. Analysis of FRH Samples from Germany (Royco 751)

Tank Serial Number	Reported Hydraulic Problem	Particulate Count Value (per 100 ml)[a] >10 μm	>20 μm	>30 μm	>40 μm	Filterable Insolubles (mg/100 ml)[b]	Flash-Point (° F)[c]	OHT Present (% WT)[d]
6775	No	170,280	24,550	870	430	7.18	395	1.78
6783	No	110,880	10,650	670	340	1.10	415	1.83
6799	No	587,840	47,280	2,960	960	5.71	395	nil
6822	No	167,350	6,080	2,470	1,480	11.63	420	nil
6828	No	145,770	21,130	4,150	1,840	3.97	420	1.11
6829	No	89,930	11,300	1,470	770	3.98	415	1.47
7232	No	186,460	25,180	5,010	2,230	4.33	410	1.27
*	Yes	118,010	5,770	1,110	410	3.45	400	nil
6723	Yes	193,490	14,070	2,690	1,170	4.82	415	0.79
6768	Yes	95,380	67,370	5,050	2,650	1.87	380	3.34
6800	Yes	169,130	31,610	9,660	4,800	3.66	420	1.87
6801	Yes	76,200	15,210	4,670	2,260	3.10	410	0.50
6836	Yes	188,380	26,270	2,990	1,550	3.90	390	1.46
6853	Yes	125,420	9,110	1,280	660	4.14	405	2.25
6862	Yes	1,459,440	906,600	370,020	169,680	17.67	385	1.58
6873	Yes	197,040	23,570	2,930	1,120	6.12	425	1.27
7225	Yes	84,270	19,160	5,470	2,280	5.13	390	0.52
7243	Yes	144,290	15,710	1,980	930	2.22	435	1.49
6791	*	241,200	13,870	8,500	5,760	14.98	405	4.24
6788	*	117,200	12,000	2,650	1,060	1.99	415	1.62

[a] Particle calibration, in accordance with ANSI B 93.28-73 using AC Fine Test Dust, counting is performed on a HI-AC Model 420 using a 5- to 150-micron sensor.

[b] ASTM F313 procedure using a 0.45-micron filter.

[c] ASTM D92.

[d] Gas-liquid chromatographic procedure.

* No markings.

Table 2. Analysis of Hydraulic Fluid Sample

SAMPLE: FA PD 5136

SOURCE: Royco, Lot 5

CONDITION: Used FRH from USMC tank 3996340 (S/N 7117) @ Camp Pickett experiencing problems.

RESULTS:

Water, % wt[a]	0.14
Chlorine, % wt[b]	0.10
Silicon, p/m[b]	6
Barium, % wt[b]	0.11
Particle Count Value (per 100 ml)[c]	
>10 μm	320,230
>20 μm	13,130
>30 μm	3,060
>40 μm	1,460

[a] ASTM D1744 (Karl Fisher Method).

[b] X-Ray Fluorescence Procedure.

[c] Paticle Calibration in accordance with ANSI B93.28-73 using ACFTD. Counting is performed on a HI-AC Model 420 using a 5- to 150-μ sensor.

Table 3. Spectrographic Analysis

Sample	Relative Amounts of Metallic Elements Present in the Filtered Residues							
	Si	Cu	Fe	Ba	B	Mg	Al	Mn
6 (FRH new)[a]	Trace	ND[f]	Trace	Major	Heavy Trace	Trace	ND	ND
10 (FRH used)[a]	Trace	ND	Trace	Major	ND	Trace	ND	ND
11 (FRH used)[b]	Major	Major	Major	Major	Trace	Trace	Trace	Trace
12 (FRH used)[c]	Major	Major	Major	Major	Heavy Trace	Trace	Trace	Trace
14 (FRH used)[d]	Major	Major	Major	Major	Heavy Trace	Trace	Trace	Trace
2 (OHT used)[e]	Trace	ND	Trace	Major	Trace	ND	ND	ND
OHT-399636 (Chrysler Serial No. 7118)	Trace	Trace	Trace	Major	Trace	ND	ND	ND

REMARKS: It should be emphasized that the total amount of residue was very small. The amounts designated as major, heavy trace, and trace are relative to one another in each individual sample. In each sample, the metallic element present in the largest quantity has been arbitrarily designated as the major element.

Emission Spectrograph data obtained on 10 mg of millipore (.45μ) + residue.

[a] Royal FA PD 5136.
[b] From reservoir USMC 339633 (Quantico).
[c] From reservoir USMC 399648 (Camp Pickett).
[d] From reservoir USMC 399643 (Camp Pickett).
[e] MIL-H-6083 Cadillac Gage Test and Filtration Stand.
[f] ND – none detected.

Table 4. Emission Spectrograph

DC-4 Grease (from Cadillac Gage) 18 Apr 75	
Si	Major element
B, Fe (each)	Heavy trace elements
Al, Ti, Cu, Na (each)	Trace elements
Thickener found in L/N 7117 spool of superelevation actuator assembly (Camp Pickett)	
Si	Major element
Ba	Low minor element
Zn, Fe, B (each)	Heavy trace elements
Mg, Mn Cr, (each) Cu, Al, Sn, Ti, Na, Ca	Trace elements

When ashed and analyzed by emission spectroscopy, the filterable insolubles from the used Royco 751 contained major concentrations of barium, silicon, and iron.

Analysis of the used Royco 751 by GLC and Mass Spectroscopy revealed the presence of Freon 113 (trichlorotrifluoroethane) and Inhibisol. The Inhibisol is 1,1,1-trichloroethane (commonly referred to as methyl chloroform).

Analysis of finely divided particles suspended in the used Royco 751 sample by filtration through a silver membrane (1.2-micron) and subsequent analysis by Electron Spectroscopy for Chemical Analysis (ESCA) revealed the major impurities to consist of barium and sulfur.

Extensive laboratory tests were undertaken at Chrysler, MERADCOM, Wright-Patterson Air Force Base, and Frankford Arsenal laboratories on samples of Royco Lot 6 obtained from storage depots and on oil samples of Royco Lot 5 obtained from operable and inoperative tanks. Extensive laboratory tests were also conducted on stored samples of Bray Oil (the other qualified FA PD 5136 fluid, Brayco Micronic 883) and also on samples of Bray Oil used as the hydrualic fluid in tanks at Fort Knox. These tests revealed that:

a. Particulate contamination was extremely high (>150,000 in 5- to 25-micron range) (Tables 1 and 2).

b. Chlorine contamination was observed (0.113 to 0.388% chlorine) (Tables 2 and 5) (from USMC tanks at Camp Pickett). (Deleterious effects of chlorinated contaminants have been documented.)[10,11]

c. Excessive water beyond saturation limits of fluid was detected (Table 5).

d. By heating Royco 751 FA PD 5136 field samples at 150° F for 16 hours, the particulate contamination levels were significantly reduced (Table 6). This was not observed with Brayco 883 or MIL-H-6083 samples.

Analyses of the particulate contaminants showed the presence of barium, silicon, iron, and sulfur (Tables 2, 3, 4, and 5) as the predominant detectable elements. The chlorine contamination (Table 5) was traced to the Inhibisol cleaning solvent used during the hydraulic system assembling process.

In the disassembly of several of the spool valve assemblies for analysis, large deposits of a colorless greaselike substance were found, particularly in the vicinity of the O-ring seals. Emission spectrographic analysis of the greaselike material revealed an elemental composition nearly identical to that of an authentic sample of DC-4 silicone grease (Table 4) obtained from the Cadillac Gage plant where it is used as an O-ring lubricant to aid in the assembly of the hydraulic valve components of the hydraulic system.

At this point in our studies, it appeared that excessive particulate contamination may have been the cause of valve malfunction.

Examination of the valve surfaces revealed no corrosion. This strongly suggested that neither chlorine nor excessive water contamination was the cause of valve malfunctioning.

Concurrent with the above analyses, studies were made on fluids from tank systems containing MIL-H-6083 hydraulic fluid. Particulate, chlorine, and water contamination levels in the latter fluids were equal to or higher than those found in FA PD 5136 field samples (Tables 1, 5, 7, and 8).

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[10] M. J. Feldsen and W. Gilbert, "Analysis of Hydraulic Fluid for Chlorine Containing Contaminants," ASLE Preprint No. 74AM-5A-3 (May 1974).

[11] M. Fainman, "Halogenated Solvents and Corrosion in Dynamic Systems," ASLE Preprint No. 74AM-5A-2 (May 1974).

Table 5. Status of FRH Field Program

Tank Serial No.	Fluid	Sample Type	p/m H_2O	Wt. % Cl	Petroleum Ether Insoluble
6915	1	A	940	.011	.010
6915	2	B	500	ND	.022
6910	1	A	850	.004	.008
6910	2	B	500	ND	.022
6911	1	A	1040	.001	.014
6911	2	B	480	ND	.022
6950	3	A	977	.139	.015
6926	3	A	788	.138	.016
6918	3	A	1575	.167	.016
6933	1	A	990	ND	.013
6933	3	B	396	ND	.022
6881	1	A	924	ND	.070
6881	3	B	396	ND	.027

Legend: Fluid 1 – MIL-H-6083 (OHT)
2 – Bray (5136)
3 – Royal (5136)

Sample Type A – Preflush
B – 1st Sample

ND – None detected

Table 6. Effect of Heating on Particulate Count Values

Sample Description[b]	Test Conditions	Particle Count Value (per 100 ml)[a]			
		>10 μm	>20 μm	>30 μm	>40 μm
FRH, Chrysler Plant Supply	Room Temp	226,777	7,713	780	260
FRH, Chrysler Plant Supply	16 hr @ 150° F	10,483	1,030	270	143
FRH, Lot 6, Letterkenny Depot	Room Temp	4,545	855	330	175
FRH, Lot 6, Letterkenny Depot	16 hr @ 150° F	3,747	1,080	470	300
FRH, Lot 6, Letterkenny Depot	Room Temp	295,800	23,870	4,740	1,470
FRH, Lot 6, Letterkenny Depot	16 hr @ 150° F	41,697	5,503	1,417	583

[a] Particle Calibration in accordance with ANSI B93.28-73 using ACFTD. Counting is performed on a HI-AC Model 420 using a 5- to 150-μ sensor.

[b] FRH samples listed are FA PD 5136 supplied by Royal Lubricants Co. Royco 751.

Table 7. Analysis of Hydraulic Fluid Samples

Fluid	Condition	Origin	Filterable Insolubles (mg/100 ml)[a]	Particle Count Values (per 100 ml)[b] >10 μm	>20 μm	>30 μm	>40 μm	Flash-Point (° F)[c]	Flash-Point (° F)[d]
MIL-H-5606C	New	Ft. Belvoir Supply	0.88	51,600	16,130	5,570	3,230	ND[e]	ND
MIL-H-83282	New	Ft. Belvoir	18.43	16,500	5,640	2,840	1,760	ND	ND
MIL-H-83282+BDNS[f]	New	Ft. Belvoir	6.14	101,290	3,830	1,170	700	ND	ND
MIL-H-6083D	Used[g]	Ft. Knox	6.21	714,160	33,980	5,380	1,920	190	205
FA PD 5136	New	Brayco, Ft. Knox	3.64	5,200	1,960	810	380	425	480
FA PD 5136	New	Brayco, Ft. Knox	2.09	4,350	1,470	660	450	410	480
FA PD 5136	Used[h]	Brayco, Ft. Knox	11.90	221,090	7,110	1,390	400	330	380
FA PD 5136	Used[i]	Brayco, Ft. Knox	11.70	26,205	28,570	5,510	2,090	395	420
FA PD 5136	New	Royco, Lot 6, Letterkenny Depot	7.65	166,080	28,990	8,230	3,000	ND	ND
FA PD 5136	New	Brayco, Ft. Hood	2.22	5,350	1,230	590	360	410	465

[a] ASTM F313 method using 0.45-μ membrane filter.

[b] Particle Calibration in accordance with ANSI B93.28-73 using ACFTD. Counting is performed on a HI-AC Model 420 using a 5- to 150-μ sensor.

[c] ASTM D92.

[d] ASTM D92.

[e] Not determined.

[f] 2.5 wt. % of Barium Dinonylnaphthalenesulfonate was used.

[g] Removed from M60A1 (AOS) S/N 5894 after 2195 miles' operation.

[h] Removed from M60A1 (AOS) S/N 6459 after 221 miles' operation.

[i] Removed from M60A1 (AOS) S/N 5837 after 14 miles' operation.

Table 8. Sample Analyses of Hydraulic Fluids

Fluid	Condition	Tank Sample	Origin	Filterable Insolubles (mg/100 ml)[a]	Particulate Count Values (per 100 ml)[b]			
					>10 μm	>20 μm	>30 μm	>40 μm
MIL-H-6083D	New	No	Cad. Gage Supply	1.7	1,740	343	220	150
MIL-H-6083D	New	No	Cad. Gage Test Stand	2.4	1,170	330	110	65
MIL-H-6083D	New	No	Chrys. Plant Supply	2.2	2,930	850	370	200
MIL-H-6083D	New	No	Chrys. Plant Test Stand	1.8	2,930	900	310	153
MIL-H-6083D	Used	USMC 399638	Camp Pickett	3.0	122,100	41,510	18,870	8,830
MIL-H-6083D	Used	USMC 399640	Camp Pickett	1.7	56,990	13,560	5,470	2,400
MIL-H-6083D	Used	USMC 399648	Camp Pickett	1.9	76,570	18,180	7,970	3,930
FA PD 5136	New	No	Chrys. Supply, Royco, Lot 5	5.9	172,560	3,500	620	360
FA PD 5136	New	No	Chrys. Stand, Royco, Lot 5	2.0	4,680	710	360	160
FA PD 5136	New	No	Letterkenny, Royco, Lot 6	7.8	3,500	800	310	180
FA PD 5136	New	No	Letterkenny, Royco, Lot 6	16.3	267,410	17,730	3,270	1,170
FA PD 5136	Used	USMC 339633	Quantico, Royco, Lot 5	12.9	76,520	5,330	1,690	770
FA PD 5136	Used	S/N 7126	Camp Pickett, Royco, Lot 5	10.7	221,980	10,120	1,440	400
FA PD 5136	Used	S/N 7131	Camp Pickett, Royco, Lot 5	11.9	1,743,630	73,330	14,700	7,550
FA PD 5136	Used	S/N 7129	Camp Pickett, Royco, Lot 5	6.2	320,230	13,130	3,060	1,460
FA PD 5136	Used	S/N 7123	Camp Pickett, Royco, Lot 5	6.1	570,380	101,660	28,220	9,050
FA PD 5136	Used	S/N 7117	Camp Pickett, Royco, Lot 5	8.6	86,540	7,710	2,440	1,070
FA PD 5136	Used	S/N 7119	Camp Pickett, Royco, Lot 5	7.2	180,360	30,280	7,840	2,950
FA PD 5136	Used	S/N 7130	Camp Pickett, Royco, Lot 5	4.5	207,710	9,240	2,200	970

[a] ASTM F313 method using 0.45 μ membrane filter.

[b] Particle Calibration in accordance with ANSI B93.28-73 using ACFTD. Counting is performed on a HI-AC Model 420 using a 5- to 150-μ sensor.

All of the above indicated to the Task Force Subgroup that some less obvious factors than the above contaminants were the cause of valve malfunction. Because of the relatively high water content found in the oil samples from the tanks containing inoperative valves (Table 5), it was deemed reasonable to study the effect of water on finished FA PD 5136 formulations and on each of the ingredients of the Royal and Bray FA PD 5136 formulations. The laboratory data (Figure 3) indicated that polypropylene glycol added by Royal in formulating their FA PD 5136 product caused the barium dinonylnaphthalenesulfonate rust inhibitor to precipitate from solution in the presence of moisture. This did not occur with the Bray sample, because the latter did not contain polypropylene glycol. However, when polypropylene glycol was added to the Bray formulation, the barium dinonylnaphthalenesulfonate was observed to precipitate in the presence of moisture.

Barium dinonylnaphthalenesulfonate (2.25%) was dissolved in synthetic hydrocarbon fluid. Small amounts of additives (oxidation inhibitor, metal deactivator, antiwear) were added separately to this solution and stirred. No visible reaction occurred in the test tubes to which the additive had been added. The solution to which polypropylene glycol had been added turned hazy after 1 minute. This haze continued to intensify and after 5 minutes the presence of a precipitate was evident. The precipitate was filtered off and washed quickly with hexane. An infrared analysis of the residue showed it to be barium dinonylnaphthalenesulfonate.

The above series was repeated with 2.25% sulfonate dissolved in Royal's ester mix instead of in the synthetic hydrocarbon fluid. No precipitation or haziness occurred upon addition of any of the additives. When synthetic hydrocarbon fluid was added to the test tube containing polypropylene glycol plus sulfonate dissolved in ester mix, a haziness again appeared and precipitation followed.

Figure 3. Laboratory data – solubility studies.

In order to corroborate the above laboratory findings, a series of simulated performance hydraulic valve system tests were carried out by Cadillac Gage. In each case, fluids were intentionally contaminated with: (a) 5 wt. % of OHT containing 3 wt. % of Inhibisol, (b) 1800 p/m of synthetic sea water (ASTM D 665), (c) 3 grams Arizona dust (MIL-D-13570), and (d) 1 gram of DC-4 (silicon grease) to simulate the contaminants found in field tank systems and average operational tank cycles. These studies were conducted on Bray, Royal, and Mobil products qualified under MIL-H-46170 (FA PD 5136) and MIL-H-83282 samples. System failures occurred only with

the Royal lubricants FA PD 5136 products.[12] Examination of the valve surfaces on the failed components indicated a deposit which appeared to be similar to the deposit found in Wright-Patterson Air Force Base analysis of the coating of the spool from the tanks at Quantico. To confirm these two series of tests (laboratory analyses and Cadillac Gage tests), a control field test was authorized and implemented at Fort Polk. This involved 40 M60A1 (AOS) tanks, 21 filled with Bray FA PD 5136 and 19 filled with Royal FA PD 5136, Lot 5.

In October 1975, 18 of the 19 Royal-filled tanks had become inoperative because of stuck power spool valves in gunner valve control assemblies (Figure 2) and azimuth and elevating spool valves (Figure 4). No stuck valves were noted on 21 tanks using Bray Oil Company's FA PD 5136 hydraulic fluid. A large number of the stuck valves were removed from the tanks and forwarded to Chrysler Laboratories for inspection, study, and distribution (Table 5). Deposits of thin amber and/or brown films were noted on many of the spool valves. A typical illustration is given in Figure 5. (The films were not adherent and could be scraped off readily. Several spools with the film deposits were distributed to Air Force Materials Laboratory, Chrysler Laboratories, and Frankford Arsenal for analyses. A compilation of the data indicated that the film deposits contain barium, sulfur, silica, iron, oxygen, and base oil (Tables 5, 9, 10, and 11). Techniques used were Scanning Electron Microscopy, Spark Source Mass Spectrometry, Energy Dispersive X-Ray, Infra-Red Spectroscopy, and Electron Spectroscopy for Chemical Analysis (ESCA).

Table 9. Summary of Energy Dispersive X-Ray Analysis

	Elements Detected		
Sample Identification	Major	Minor	<Minor
Film on metal treated with pet ether	Fe	Ba, S	Si, Ca, Mn
Base metal	Fe	--------	Cr, Mn, Si, S
Clean oil	--------	--------	Si, P, S, Ba, (Fe?)

Note: (Fe?) may be due to instrumental conditions.

[12] J. E. Cottle, "Test Report Hydraulic Fluid Comparison Tests," M60A1, Chrysler Defense Engineering Work Directive No. L2401002, Contract No. 0241 (January 1976).

Table 10. Relative Intensity ($X10^3$) and Binding Energy of M60A1 Spool Valve Deposits

	C1s @285		O1s @531		S2p3 @163		Ba3d3 @797		Ba3d5 @781		Nals @1071		Nls @399	
	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B
Contamination layer	40.6	286.2	16.6	534.0	0.35	169.8	8.30	797.3	11.1	782.0	0.30	1074.0	ND	ND
2-min etch	48.0	284.6	6.2	532.8	0.25	163.6	6.70	796.2	9.5	781.0	1.30	1073.2	ND	ND
Standard	12.0	285.4	4.0	533.0	0.45	169.2	5.10	797.3	7.0	782.0	0.30	1075.3	ND	ND
2-min etch	11.6	284.9	1.8	532.6	0.10	163.3	4.10	796.3	6.0	781.1	ND	ND	ND	ND

ND – Not determined.

Table 11. Corrected Intensity ($X10^3$) and Corrected Binding Energy of M60A1 Spool Valve Deposits

	C1s @285		O1s @531		S2p3 @631		Ba3d3 @797		Ba3d5 @781		Nals @1071		N1s @399		Ba3d5/S	
	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B	RI	E_B
Cali. Fac.	1.00		2.85		1.155		17.0		24.8		7.99		1.78			
Contamination layer as-rec'd	40.6	285	5.82	532.8	0.303	168.6	0.488	796.1	0.447	780.8	0.037	1072.8	ND	ND	1.475	
2-min etch	48.0	284.6	2.17	532.8	0.216	163.6	0.394	796.2	0.383	781.0	0.162	1073.2	ND	ND	1.77	
Standard	12.0	285	1.40	532.6	0.389	168.8	0.300	796.9	0.282	781.6	0.037	1074.9	ND	ND	0.725	
2-min etch	11.6	284.9	0.631	532.6	0.086	163.3	0.241	796.3	0.242	781.1	ND	ND	ND	ND	2.81	
		C1		0		S		Ba		Ba						

RI – Relative peak intensity corrected for photo-electric cross-section relative to C1s = 1.0.

E_B – Binding energy corrected for sample charging relative to C1s = 285eV.

ND – Not determined.

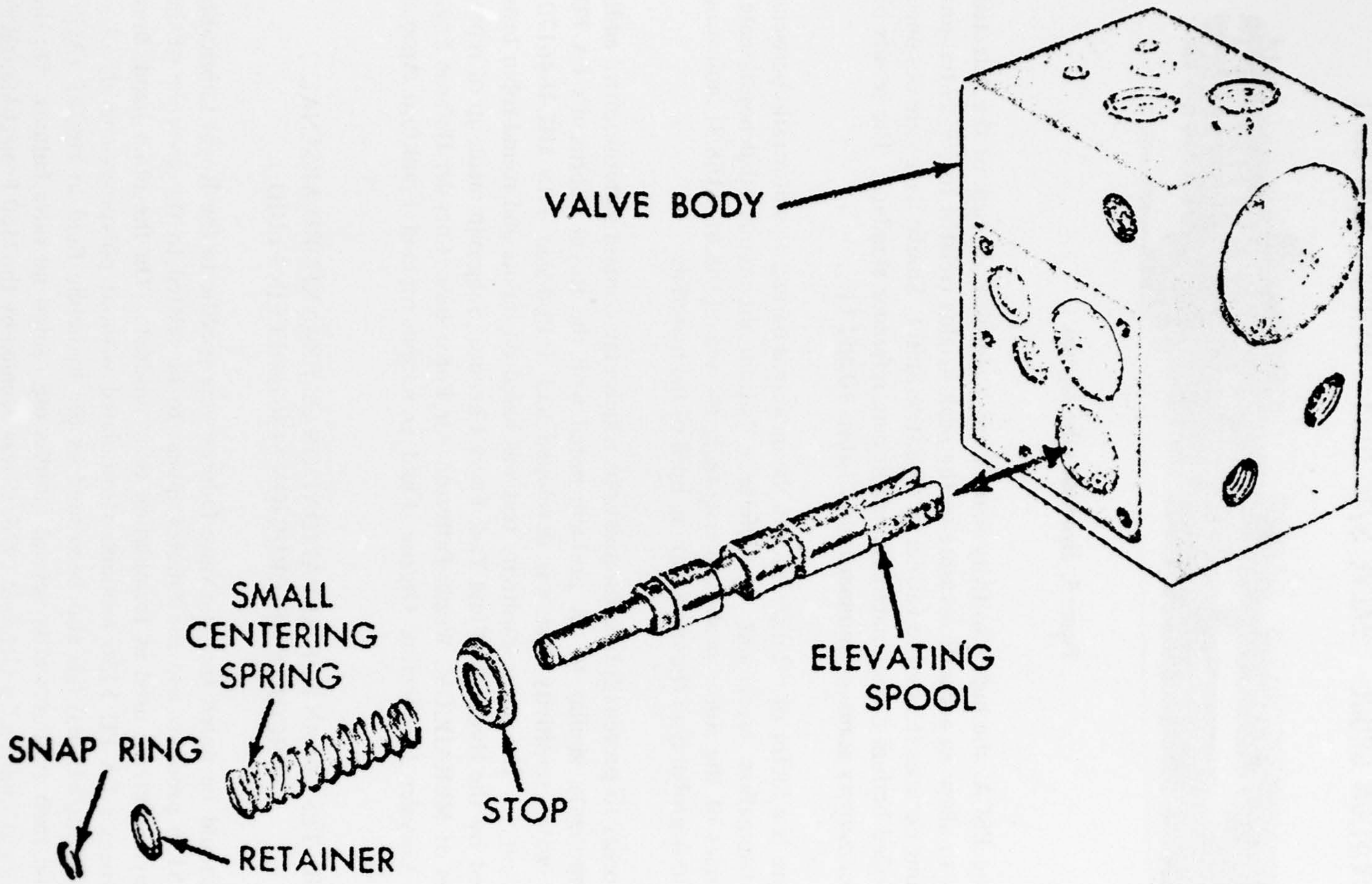

Figure 4. M60A1 gun and turret hydraulic system – elevating spool.

ELEVATION SPOOL VALVE S/N 3084 VEHICLE S/N 6881

Figure 5. Hydraulic valve deposits.

Using ESCA, the high sensitivity scans were performed for each of the detected elements to allow an accurate measure of the peak heights (related to concentration) and binding energies (related to valence or oxidation state). Similar data were obtained on a de-oiled barium dinonylnaphthalenesulfonate reference standard. The results of the high-sensitivity scans are summarized in Tables 10 and 11.

There is a factor of ~2 difference in the measured barium to sulfur ratio between the contamination layer and the reference barium dinonylnaphthalenesulfonate. The energies of the sulfur peaks are essentially the same (168.6 vs 168.3) indicating that sulfur is probably in the same form in both of the materials.

In order to prevent future formulations which may contain water-sensitive additive components, similar to the problem noted with the Royal Lubricant's FA PD 5136, a water sensitivity test was developed and introduced into MIL-H-46170, Amendment 1. The water sensitivity test was based on inputs and round-robin tests conducted by the Hydraulic Fluid Task Force Chemical Subgroup made up of representatives of MERADCOM, Wright-Patterson Air Force Base, Chrysler Defense Engineering, Chrysler Engineering Organic Fluid Development, and Frankford Arsenal (Table 12).

III. TEST PLAN FOR REVALIDATION OF FRANKFORD ARSENAL PURCHASE DESCRIPTION 5136 α-OLEFIN FLUID

It should be noted that the valve failures were specific to the Royal Lubricants FA PD 5136 products and the failures appear to be related to the presence of the polypropylene glycol used in formulating their products. On the other hand, Bray Oil Company's FA PD 5136 products (formulated without polypropylene glycol as one of the ingredients) has also been used as the hydraulic fluid in M60A1 (AOS) tanks, and their products after several months use caused no valve failures. On the basis of these findings, in October 1975, it was decided by the M60 Project Manager's

Table 12. Cooperative Water Sensitivity Test Results[a]

Test Fluid	Laboratory A	Laboratory B	Laboratory C
Hydraulic 1[b]			
Water content (p/m), initial	ND[f]	460	ND
Water content, after test	ND	3460	ND
% Light transmittance	99	110	106
Hydraulic 2[c]			
Water content (p/m), initial	ND	ND	ND
Water content, after test	ND	ND	ND
% Light transmittance	97	99	126
Hydraulic 3[d]			
Water content (p/m), initial	ND	530	ND
Water content, after test	ND	2530	ND
% Light transmittance	25	35	23
Hydraulic 4[e]			
Water content (p/m), initial	ND	500	ND
Water content, after test	ND	2660	ND
% Light transmittance	>100	110	ND

[a] Addition of 0.2% distilled H_2O to 250 ml fluid. After hand agitation, fluid was allowed to sit for 24 hours. Light transmittance is then measured @ 540 mm.

[b] FA PD 5136 Brayco BLJ2 Fluid.

[c] FA PD 5136 Mobil RM 236A Fluid.

[d] FA PD 5136 Royco Lot 6 Fluid.

[e] MIL-H-6083D Penrico C-635 Fluid.

[f] Not determined.

Office to undertake a revalidation program to be conducted by Chrysler Defense Engineering prior to reinstating the MIL-H-46170 products in the M60A1 (AOS) tanks (Table 13). Accordingly, MIL-H-6083 fluid has been drained from approximately 280 M60A1 (AOS) tanks and the Bray Oil Company's MIL-H-46170 has been substituted. These tanks with the MIL-H-46170 Bray Oil are now being monitored at four bases (Fort Polk, Fort Bliss, Fort Knox, and Fort Hood) throughout the United States. After 10 months' use, no valve failures had occurred.[13] The resubstitution of MIL-H-46170 in U. S. Army tanks will depend on the field of performance of the tanks after one year's use.

[13] L. A. Spencer, et al, "Final Report M60A1-AOS Tank Fire Retardant Hydraulic Oil Comparison Test," Defense Division Chrysler Corp., Centerline, Michigan, Contract DAAE-07-74-C-0241 (February 1976).

Table 13. FRH Oil Validation and Re-Release

1.	Specification Revision	F/A	├──┤ Dec 75	
2.	Lab Qualification (Bray & Mobil)	F/A	├──┤ Feb 76 (Final Rpt)	
3.	Environmental Test M60A1 & M60A2	APG	├ Jan 76 ┤ Apr 76 (Final Rpt)	
4.	Durability Test M60A1	CDD	├ Nov 75 ┤ May 76 (Final Rpt)	
5.	Field Validation	CDD		
	Fort Knox (315)		├ Jan 75 ┤ Jan 76 54 Tanks May 76 ┤ ▲Add 34 M60A2	(106)
	Fort Bliss (52)	Apr 75	├──┤ 17 Tanks ----┤	(50)
	Fort Polk (99)	Jun 75	├ 20 ┤ ----┤	(97)
	Fort Hood (376)		----┤	(54)
	542		105	307
	Field Monitor @ 60-day Interval			
6.	System Teardown & Insp			*May 1976
7.	Program Review			*Jun 76
8	Decision to Release (CONUS, OCONUS and Production)			*Sep 76

IV. SUMMARY

An overall summary of the data indicate that the incidents of stuck valves are specific to the FA PD 5136 Royal Lubricants products only. Bray Oil Company's FA PD 5136 products (superseded by MIL-H-46170) are also being used in M60A1 (AOS) tanks, but to date, after 10 months' use, no failure incidents have been reported.[14] Royal Lubricants FA PD 5136 products contained polypropylene glycol while Bray Oil Company's FA PD 5136 products did not. It would appear, therefore, that the cause of the problem based on the data seems to point to the polypropylene glycol additive used in formulating the Royal FA PD 5136 fluids. The additive causes the barium dinonylnaphthalenesulfonate rust inhibitor to precipitate in the presence of moisture, thereby forming a deposit on the spools which prevents their movement.

These findings, indeed, clearly delineate the cause of the "stuck valves," and safeguards have been initiated to avoid future occurrences by incorporating the "water sensitivity test" into the specification.

Since the polypropylene glycol additive will not be used in future formulations of MIL-H-46170 (composition data of the latter is now mandatory for qualification), a more detailed explanation of the mechanism of the interaction of the polypropylene glycol with barium dinonylnaphthalenesulfonate and/or the other ingredients (in the presence of moisture) used in formulating Royco 751 appears to be beyond the scope of this investigation.

V. CONCLUSIONS

On the basis of the extensive cooperative investigations conducted by the five author laboratories, the following conclusions for M60A1 (AOS) tank hydraulic systems are submitted:

a. MIL-H-6083 fluid will be replaced by MIL-H-46170 fire-resistant hydraulic fluid in production and field tanks.

b. Finer filtration of the main hydraulic system should be provided by the incorporation of an in-line 15-micron absolute disposable filter per Specification MIL-F-8815.

c. The use of chlorinated solvents and silicone greases in the preparation and assembly of hydraulic systems and components will be eliminated.

d. A replaceable drying kit should be included in the air breather cap for hydraulic fluid reservoir.

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[14] L. A. Spencer, et al, "Final Report M60A1-AOS Tank Fire Retardant Hydraulic Oil Comparison Test," Defense Division Chrysler Corp., Centerline, Michigan, Contract DAAE-07-74-C-0241 (February 1976).

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